

BACKGROUND OF THE INVENTION

5 The present invention relates to an optical
material and an optical system using it and, more
particularly, to a low refractive index high-dispersion
optical material, for example, applicable to optical
elements such as lenses, filters, mirrors, refracting
0 optical elements, diffracting optical elements, and so
on, and an optical system of optical equipment such as
cameras, binoculars, microscopes, and so on, using the
optical material.

15 As one of conventional approaches to correction
for chromatic aberration of the optical system composed
of only refracting optics, there is a method of
combining glass materials of different dispersion
characteristics. For example, in the case of
20 objectives of telescopes etc., axial chromatic
aberration is corrected for by combining a positive
lens of a low-dispersion glass material with a negative
lens of a high-dispersion glass material. For this
reason, there were cases where chromatic aberration was
25 not corrected for adequately if the composition or the
number of lenses was limited or if available glass
materials were limited.

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Comparing them herein as to refraction of rays, a ray appears as one ray even after refracted by a lens surface, whereas a ray appears as a plurality of rays of plural orders after diffracted by a diffractive surface.

When the diffracting optical element is used as a lens system, it is thus necessary to determine the grating structure so as to concentrate light of the used wavelength range into specific orders (which will also be referred to hereinafter as "designed orders") by adequately enhancing the diffraction efficiency of rays of the designed orders. When light is concentrated in the specific orders, the intensity of rays of diffracted light of the other orders is low.

When the intensity is zero, diffracted light thereof appears null. If there exist rays of diffraction orders other than the designed orders, they will be focused at positions different from those of the rays of the designed orders and appear as flare light.

The layouts capable of reducing this decrease of diffraction efficiency are presented in Japanese Patent Application Laid-Open No. 9-127321 and Japanese Patent Application Laid-Open No. 11-44808. The layouts realize high diffraction efficiency in a wide wavelength range by optimizing dispersion properties and thicknesses of gratings of materials different from each other.

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For further enhancing the optical performance of the aforementioned diffracting optical elements, we investigated the optical materials commercially available, or the optical materials under research and development and obtained the distribution as illustrated in Fig. 1.

The materials of the stack diffracting optical elements described in the Japanese Patent Applications Laid-Open No. 9-127321 and Laid-Open No. 11-44808 also fall in the distribution of Fig. 1.

As for the materials suggested in the
aforementioned Japanese Patent Applications Laid-Open
No. 6-32631 and Laid-Open No. 61-9262 and Japanese
Patent Publication No. 4-33740, their refractive
indexes and refractive-index dispersions are ($n_d = 1.585$
to 1.660, $v_d = 40.5$ to 32.5), ($n_d = 1.5945$ to 1.6925, v_d
 $= 27.3$ to 36.6), and ($n_d = 1.55$ to 1.65, $v_d = 27$ to 35),
respectively, and these materials also fall in the
distribution of the existing substances of Fig. 1.

It is seen that 2-ethoxy-ethyl methacrylate ($n_d = 1.483$, $v_d = 32$) seems only one material with low refractive index and high dispersion and that there have been few such materials developed.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an optical material with low refractive index and high

dispersion, which was not known heretofore, and an optical system using it.

A first aspect of the present invention is an optical material which is a mixture of materials comprising a first material having a refractive index of not more than 1.45 for the d-line and a second material having an Abbe's number, indicating wavelength dispersion in the visible region, of not more than 25, wherein a relation between the refractive index for the d-line (n_d) and the Abbe's number (v_d) indicating the wavelength dispersion in the visible region is defined as follows:

$$n_d \leq -6.667 \times 10^{-3} v_d + 1.70.$$

15 A second aspect of the invention is the optical material of the first aspect wherein said Abbe's number (v_d) indicating the wavelength dispersion in the visible region is less than 40.

20 A third aspect of the invention is the optical material of the first aspect or the second aspect wherein said second material comprises particles having the grain size in the range of 2 to 100 nm.

A fourth aspect of the invention is the optical material of the first aspect, the second aspect, or the third aspect wherein said first material is an amorphous fluororesin.

A fifth aspect of the invention is the optical material of either one of the first to fourth aspects

wherein said second material is particles of a composite metal oxide of titanium and silicon ($\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$) having the Abbe's number (v_d) of 24.4.

A sixth aspect of the invention is the optical material of either one of the first to fifth aspects wherein said first material is an amorphous fluororesin, said second material is particles of a composite metal oxide of titanium and silicon ($\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$) having the Abbe's number (v_d) of 24.4, and a weight ratio of the particles and said amorphous fluororesin is in the range of 45:100 to 75:100.

A seventh aspect of the invention is the optical material of the first aspect, the second aspect, or the third aspect wherein said first material is a dimethylsilicone resin.

An eighth aspect of the invention is the optical material of either one of the first to third aspects and the seventh aspect wherein said second material comprises particles of titanium oxide (TiO_2).

20 A ninth aspect of the invention is the optical material of the first aspect, the second aspect, or the third aspect wherein said first material is a dimethylsilicone resin, said second material is particles of titanium oxide (TiO_2), and a weight ratio of the titanium oxide and said dimethylsilicone resin is in the range of 18:100 to 70:100.

A tenth aspect of the invention is an optical

material wherein a relation between a refractive index for the d-line (n_d) and an Abbe's number (v_d) indicating wavelength dispersion in the visible region satisfies the following condition:

$$n_d \leq -0.01v_d + 1.70.$$

An eleventh aspect of the invention is an optical material which is a mixture of materials comprising a first material having a refractive index of not more than 1.40 for the d-line and a second material having an Abbe's number, indicating wavelength dispersion in the visible region, of not more than 15, wherein a relation between the refractive index for the d-line (n_d) and the Abbe's number (v_d) indicating the wavelength dispersion in the visible region is defined as follows:

$$n_d \leq -0.01v_d + 1.70.$$

A twelfth aspect of the invention is the optical material of the tenth aspect or the eleventh aspect wherein said Abbe's number (v_d) indicating the wavelength dispersion in the visible region is not more than 40.

A thirteenth aspect of the invention is the optical material of the eleventh aspect wherein said second material comprises particles having the grain size in the range of 2 to 100 nm.

A fourteenth aspect of the invention is the optical material of the eleventh aspect or the

A fifteenth aspect of the invention is the optical material of the eleventh aspect, the thirteenth aspect, or the fourteenth aspect wherein said second material comprises particles of titanium oxide (TiO_2).

A seventeenth aspect of the invention is an optical material which is a mixture of materials comprising a first material having a refractive index for the d-line in the range of 1.45 to 1.55 both inclusive and a second material having an Abbe's number, indicating wavelength dispersion in the visible region, of not more than 10, wherein a relation between the refractive index for the d-line (n_d) and the Abbe's number (v_d) is defined as follows:

$$n_d \leq -6.667 \times 10^{-3} v_d + 1.70.$$

25 An eighteenth aspect of the invention is the optical material of the seventeenth aspect wherein said Abbe's number (v_d) indicating the wavelength dispersion in the visible region is not more than 40.

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A twenty fourth aspect of the invention is the optical material of either one of the seventeenth to twentieth aspects wherein said first material is an

5 A twenty fifth aspect of the invention is the optical material of either one of the seventeenth to twentieth aspects wherein said first material is a copolymer of methyl methacrylate and styrene.

A twenty seventh aspect of invention is an optical member comprising the optical material as set forth in either one of the first aspect to the twenty sixth aspect.

A twenty ninth aspect of the invention is a diffracting optical element using the optical material as set forth in either one of the first aspect to the twenty sixth aspect.

A thirtieth aspect of the invention is an optical

A thirty first aspect of the invention is an optical device comprising the optical system of the
5 twenty eighth aspect or the thirtieth aspect.

15 A thirty third aspect of the invention is an optical member comprising the material produced by the production method as set forth in the thirty second aspect.

A thirty fifth aspect of the invention is the optical system of the thirty fourth aspect wherein said optical member is a diffracting optical element.

25 A thirty sixth aspect of the invention is an optical device comprising the optical system of the thirty fourth aspect or the thirty fifth aspect.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an explanatory diagram to show the relationship between refractive index and dispersion of optical materials;

5 Fig. 2 is an explanatory diagram to illustrate a structure with a reduced filling factor of a substance;

Fig. 3 is an explanatory diagram to show the relationship between refractive index and dispersion with various filling factors of a substance;

10 Fig. 4 is an explanatory diagram to explain
dispersion of a high dispersion material into a low
index material;

Fig. 5 is an explanatory diagram to illustrate the relationship between refractive index and dispersion in mixtures of low index materials and high dispersion materials;

Fig. 6 is an explanatory diagram to show types of mixtures of substances;

Fig. 7 is a cross-sectional view of the main part
20 of a diffracting optical element;

Fig. 8 is a cross-sectional view of the main part of another diffracting optical element;

Fig. 9 is a diagram to show the relationship between refractive index and dispersion in Example 1 and Comparative Example 1;

Fig. 10 is a diagram to show the relationship between refractive index and dispersion in Example 2;

10 Fig. 14 is a diagram to show the relationship
between refractive index and dispersion in Example 8.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the optical materials according to
15 the present invention will be described below.

In general, since a substance is composed of molecules or atoms, oscillator characteristics and density are determined by its atomic or molecular structure. For this reason, the optical constants, including the refractive index n_d for the d-line (light of the wavelength 587 nm), the Abbe's number v_d indicating wavelength dispersion in the visible region, etc. of the optical materials, show the distribution as illustrated in Fig. 1. The relation between refractive index n and polarization χ' of substance can be expressed by the following Equation (1).

$$n^2 = 1 + \chi' \quad (\text{Eq. 1})$$

Supposing particles have the size of 2 to 100 nm, the polarization characteristics inside the particles will be like those of bulk. However, in the case of a structure with a reduced filling factor of substance as illustrated in Fig. 2, the polarization characteristics for the light in the visible wavelength range of 400 to 700 nm are of a level in which nonuniformity thereof can be ignored in an optical sense. Therefore, the structure as illustrated in Fig. 2 demonstrates the optical characteristics close to the Drude theory of Eq. (2) below.

$$n^2 = 1 + \chi^1 = 1 + T(n_1^2 - 1) \quad (\text{Eq. 2})$$

$(0 \leq T \leq 1)$ n_1 : refractive index of bulk

Fig. 3 is an explanatory diagram to show the relationship between refractive index n_d and Abbe's number v_d with various filling factors of substance. As seen from Fig. 3, the refractive index n_d , and dispersion v_d vary as indicated by curves S1, S2, S3, and with variation in apparent density by changing the filling factors, the refractive index demonstrates change while the Abbe's number little change.

Therefore, a substance can be prepared in the region of $(n_d \leq -6.667 \times 10^{-3}v_d + 1.70, v_d \leq 40, \text{ and } n_d \leq -0.01v_d + 1.70, v_d \leq 40)$ by decreasing the refractive index in the structure of Fig. 2.

When an antireflection film is formed on a surface of a lens by vapor deposition or the like, the filling factor of the film is lowered depending upon conditions of deposition and the structure becomes as illustrated in Fig. 2, whereby the refractive index of the material with large wavelength dispersion (small Abbe's number v_d) is decreased to some extent.

However, if the filling factor of the substance is too low as in (2) of Fig. 4, there will appear such a tendency that when the substance is exposed from vacuum to the ordinary atmosphere, molecules of air and water adsorb thereto because of its porous structure, so as to impede the decrease of refractive index and increase the Abbe's number as well. In addition, the substance becomes very fragile.

Therefore, a material with a low refractive index and high dispersion (small Abbe's number) is realized by first decreasing the filling factor of the substance with large wavelength dispersion of refractive index (hereinafter referred to as "dispersion") (a high-dispersion substance) and filling gaps in this substance with another low-index substance with a small refractive index, as in (3) of Fig. 4.

Refractive indexes and Abbe's numbers were calculated according to Eq. (3) below and based on the polarizability obtained by Eq. (1), for mixtures based on the assumption that the material with high

refractive index and large dispersion has $(n_d, v_d) = (2.74, 11.1)$, or $(3.31, 8.40)$ and the substance with low refractive index and small dispersion has $(n_d, v_d) = (1.29, 87.4)$, $(1.34, 73.0)$, or $(1.43, 57.5)$.

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$$\begin{aligned} n^2 &= 1 + T\chi^1 + (1 - T)\chi^2 \\ &= 1 + T(n_1^2 - 1) + (1 - T)(n_2^2 - 1) \quad (\text{Eq. 3}) \end{aligned}$$

$(0 \leq T \leq 1)$ n_x : refractive index of bulk of each material.

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The results are as illustrated in Fig. 5 and the optical materials are realized in the region of $(n_d \leq -6.667 \times 10^{-3}v_d + 1.70, v_d \leq 40)$ by mixing the low-index material $(n_d \leq 1.45)$ with the large-dispersion material (high-dispersion material, $v_d \leq 25$).

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In this case, there is such a tendency that even in fixed proportions, the dispersion shows little change but the refractive index does a shift toward lower indexes when the high-index high-dispersion material is mixed with a lower-index material; and the refractive index demonstrates little change but the dispersion increases when the high-index high-dispersion material is mixed with a higher-dispersion material.

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For mixing the large-dispersion material with the low-index material, any method may be employed as long as the size is smaller than the wavelengths of light and makes little contribution to scattering (i.e., if

the size is in units not more than 100 nm).

Specifically, the following mixing ways are considered, as illustrated in Fig. 6;

where the high-dispersion material is of fine particles,

(1) normal mixing;

where the main chain is an organic polymer,

(2) guest-host type mixing,

(3) main chain type mixing, and

(4) side chain type mixing.

In the case of the film formation by vacuum vapor deposition, applicable methods include two-dimensional evaporation of the large-dispersion material and the low-index material, formation of equivalent layers by depositing the respective materials in units of several nm, and so on.

However, as the units indicating high dispersion of polarizability become 2 nm or less to go into the molecular level, the environment of the high-dispersion units becomes far from the bulk state and tends to follow the Lorentz-Lorenz theory (Eq. (4)) with consideration to local electric fields, rather than the Drude theory. In this case, where the materials are mixed in fixed proportions, the dispersion tends to be lower, as compared with Eq. (3).

ρ_x : density in bulk of each material

There are no specific restrictions on the large-dispersion material ($v_d \leq 25$), but specific examples thereof are TiO_2 ($n_d, v_d = 2.2652, 11.8$), Nb_2O_5 ($n_d, v_d = 2.367, 14.0$), ITO ($n_d, v_d = 1.8581, 5.53$), Cr_2O_3 ($n_d, v_d =$

The optical material in the region of ($n_d \leq -6.667$
5 $\times 10^{-3}v_d + 1.70$, $v_d \leq 40$) can be realized by using the
low-index material of $n_d \leq 1.45$ and particles of the
large-dispersion material of $v_d \leq 25$ in the grain size
of 2 to 100 nm.

There are no specific restrictions on the material with large dispersion (i.e., with a small Abbe's number), but it is desirably particles of a composite metal oxide of titanium and silicon ($\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$). The ratio of metals can be adjusted to an arbitrary value for the composite metal oxide of titanium and silicon and it is thus easy to adjust the Abbe's number. The large-dispersion material used herein is the particles of the composite metal oxide of titanium and silicon adjusted to the Abbe's number (v_d) of $24.5 \leq 25$.

There are no specific restrictions on the grain size of the particles of the composite metal oxide of

For uniformly dispersing the above particles of
5 (Si_x-Ti_(1-x)O₂), for example, in the above amorphous
fluororesins, it is effective to modify the surface of
the particles of (Si_x-Ti_(1-x)O₂) by a fluorophilic group
like the fluoroalkyl group.

As described above, the optical material in the
15 region ($n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$) is obtained
by mixing the material with the low index ($n_d \leq 1.45$)
and the material with the large wavelength dispersion
of refractive index ($v_d \leq 25$).

The aforementioned material, 2-ethoxy-ethyl methacrylate, is considered to be a material realizing ($n_d = 1.483$, $v_d = 32$) by decreasing the density in terms of the structure, but the structure of this 2-ethoxy-ethyl methacrylate is different from that of the optical material in the region ($n_d \leq -6.667 \times 10^{-3} v_d +$

1.70, $v_d \leq 40$) prepared by forming the mixture of the material with the low index ($n_d \leq 1.45$) and the large-dispersion material ($v_d \leq 25$) in the present embodiment. In addition, the method with this 2-ethoxy-ethyl methacrylate provides less freedom for adjusting the levels of refractive index and wavelength dispersion than the method of the present embodiment.

As another example, the optical material is realized in the region of ($n_d \leq -0.01v_d + 1.70$, $v_d \leq 40$) by using the low-index material of $n_d \leq 1.40$ and particles with $v_d \leq 15$ and in the particle size of 2 to 100 nm as the large-dispersion material.

There are no specific restrictions on the low-index material for realizing this optical material, but the low-index material is desirably one of the amorphous fluororesins. The reason is that the amorphous fluororesins have the low refractive indexes, are stable and less reactive, and thus give rise to less deviation from calculated values in the form of mixtures.

There are no specific restrictions on the large-dispersion material for realizing the above optical material, but it is desirably particles of TiO_2 . The reason is that the TiO_2 particles are relatively easily available and belong to the class of materials indicating the highest dispersion out of the particles for optical use commercially available commonly.

There are no specific restrictions on the particle size of the TiO_2 particles as long as it does not cause unignorable scattering of light. The particle size is preferably not more than 100 nm.

For uniformly dispersing the above TiO_2 particles, for example, in the aforementioned amorphous fluororesins, it is effective to modify the surface of the TiO_2 particles by a fluorophilic group like the fluoroalkyl group.

When the mixing ratio of the fluoro-resin and titanium oxide (TiO_2) is in the range of 7:100 to 90:100, the optical material obtained satisfies the region ($n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$); when the ratio is in the range of 90:100 to 40:100, the optical material satisfies the region ($n_d \leq -0.01v_d + 1.70$, $v_d \leq 40$).

By mixing the low-index material ($n_d \leq 1.40$) with the large-dispersion material ($v_d \leq 15$) in this way, the optical material can be obtained in the region ($n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$) or in the region ($n_d \leq -0.01v_d + 1.70$, $v_d \leq 40$).

Among the materials such as TiO_2 (n_d , $v_d = 2.2652$, 11.8), Nb_2O_5 (n_d , $v_d = 2.367$, 14.0), ITO (n_d , $v_d = 1.8581$, 5.53), Cr_2O_3 (n_d , $v_d = 2.2178$, 13.4), BaTiO_3 (n_d , $v_d = 2.4362$, 11.3), etc. being large-dispersion materials, ITO (n_d , $v_d = 1.8581$, 5.53) has the Abbe's number (v_d) of half or less those of the other high-dispersion

materials and thus demonstrates extremely high dispersion.

For that reason, as to ITO ($n_d, v_d = 1.8581, 5.53$), even if the low-index material is a material having the index of $n_d \geq 1.45$ but $n_d \leq 1.55$, the resultant optical material satisfies the region of ($n_d \leq -6.667 \times 10^{-3}v_d + 1.70, v_d \leq 40$).

The mixing material as the substance of $n_d \leq 1.55$ can be selected from the general-purpose optical materials as typified by polymethyl methacrylate (hereinafter referred to as PMMA; $n_d = 1.48$), amorphous polyolefin (hereinafter referred to as APO; $n_d = 1.525$), some of copolymers of methyl methacrylate and styrene (hereinafter referred to as MS; $n_d = 1.53$ to 1.571), and so on.

Since ITO is an electrically conductive substance, it can also reduce adhesion of dust to the lens surface due to charging specific to the optical resins for optical use.

Since ITO shows absorption in the ultraviolet region, it acts as a UV absorber and thus relieves deterioration of the resin due to ultraviolet rays.

The optical material in the region of ($n_d \leq -6.667 \times 10^{-3}v_d + 1.70, v_d \leq 40$) can be realized by using the material of $1.45 \leq n_d \leq 1.55$ as the low-index material and using the particles having $v_d \leq 10$ and the particle size of 2 to 100 nm as the large-dispersion material.

There are no specific restrictions on the low-index material for realizing this optical material, but it can be one of the general-purpose optical resins such as PMMA ($n_d = 1.48$), APO ($n_d = 1.525$), some of MS ($n_d = 1.533$; the refractive index differs depending upon the copolymerization ratio of methyl methacrylate and styrene monomers), and so on.

The high-dispersion material for realizing the above optical material is desirably ITO ($n_d, v_d = 1.8581, 5.53$). The reason is that there is no other material having the Abbe's number of not more than 10 in the visible region (light of 400 to 700 nm) than ITO ($n_d, v_d = 1.8581, 5.53$).

There are no specific restrictions on the particle size of the particles of ITO ($n_d, v_d = 1.8581, 5.53$) as long as it does not affect the scattering of light. However, the particle size is desirably not more than 100 nm.

For uniformly dispersing the above ITO particles, for example, in PMMA ($n_d = 1.48$), APO ($n_d = 1.525$), and some of MS ($n_d = 1.533$) described above, it is effective to modify the surface of the ITO particles with an alkyl group having the nature of being compatible with PMMA.

A low-index high-dispersion optical material satisfying the region ($n_d \leq -6.667 \times 10^{-3}v_d + 1.70, v_d \leq 40$) can be obtained in either of the following cases:

where the mixing ratio of PMMA and ITO (n_d , $v_d = 1.8581$, 5.53) is in the range of 30:100 to 250:100; where the mixing ratio of APO ($n_d = 1.525$) and ITO (n_d , $v_d = 1.8581$, 5.53) is in the range of 44:100 to 150:100; where the mixing ratio of MS ($n_d = 1.533$) and ITO (n_d , $v_d = 1.8581$, 5.53) is in the range of 43:100 to 140:100.

Since ITO is the electroconductive material, the chargeability of the above optical materials is also reduced.

The aforementioned material of 2-ethoxy-ethyl methacrylate is the material realizing ($n_d = 1.483$, $v_d = 32$) by decreasing the density in terms of the structure, but the structure thereof is different from the structure of the present optical materials in the range ($n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$) formed by mixing the low-index material ($n_d \leq 1.55$) with the large-dispersion material ($v_d \leq 10$). In addition, the method with 2-ethoxy-ethyl methacrylate provides less freedom for adjusting the levels of refractive index and index dispersion than the method of the present embodiment.

Specific examples of the optical materials according to the present invention will be described below.

<Example 1>

The particles of $\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$, the surface of which was modified with a fluorine surfactant according to

Using measurements of the reflectance and transmittance of the above mixture films, absorption-scattering (rate) was calculated according to the equation below.

5 absorption-scattering (rate) = 1 - (two-side reflectance) - (transmittance).

The results of the refractive index and dispersion are presented in Table 1 and Fig. 9.

10 The mixtures at the ratios of $\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$: amorphous fluororesin = 18.3:100 and 41.1:100 had the refractive index and dispersion of $(n_d, v_d) = (1.337, 53.9)$ and $(1.383, 41.0)$, respectively, and were off the region of $n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$. However, since the absorption-scattering (rate) of the mixtures is not more than 0.01, they can be used as optical films without problems.

15 The mixture at the ratio of $\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$: amorphous fluororesin = 70.5:100 had the refractive index and dispersion of $(n_d, v_d) = (1.427, 34.9)$, and was present within the region of $n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$. The absorption-scattering (rate) thereof was not more than 0.01, and the mixture can be used as an optical film without problems.

20 The mixture at the ratio of $\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$: amorphous fluororesin = 88.5:100 showed great scattering with the absorption-scattering (rate) of 0.04 and the refractive index and index dispersion thereof were unmeasurable.

[Method 1] Preparation of solution in which particles of $\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$ modified with fluorine base surfactant were dispersed

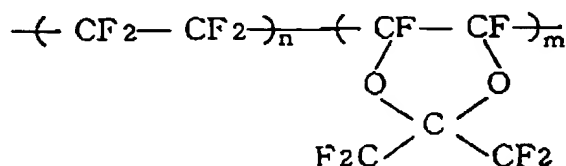
4 g of a fluorine base surfactant, N-(3-
5 (trimethoxysilyl) propyl)-N-propylperfluorooctanesulfonamide, was added to a solution containing 20 g of particles of $\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$ (5 to 20 nm) in 500 g of 2, 2, 3, 3, 3-pentafluoro-1-propanol, and thereafter the mixture was put into 0.21
10 ml of 1N hydrochloric acid. The mixture was agitated at 25°C for 24 hours to modify the surface of the particles. After that, 250 g of the fluorine solvent [the molecular structure of $(\text{C}_4\text{F}_9)_3\text{N}$] was added to the mixture and fractional distillation was conducted at
15 90°C to remove the pentafluoro propanol and isopropanol etc. made by hydrolysis, thereby obtaining the fluorine solvent solution in which the particles of $\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$ were dispersed.

<Comparative Example 1>

20 In contrast to Example 1, the particles of $\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$ with the refractive index and dispersion of $(n_d, v_d) = (1.636, 29.1)$ were used and the index dispersion of the high-dispersion material was $v_d > 25$.

The particles of $\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$, the surface of which
25 was modified with the fluorine surfactant according to [Method 1] described above and the refractive index and the index dispersion of which were adjusted to (n_d, v_d)

= (1.636, 29.1), and the amorphous fluororesin ($n_d = 1.29$) represented by the chemical formula below, were mixed at the weight ratios of $\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$: amorphous fluororesin = 17.3:100, 38.9:100, 66.7:100, and 83.8:100 in the fluorine solvent [the molecular structure of $(\text{C}_4\text{F}_9)_3\text{N}$], which was a solvent in which the amorphous fluororesin was soluble.



The percentage of the amorphous fluororesin to the solvent was 4%. A coating of each of the above solutions was formed on the substrate of BK7 of $\phi 49 \times 2t$ by the dip coat method and was heated in the furnace at 180°C for 20 minutes to obtain a film of the mixture of the amorphous fluororesin and the particles of $\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$.

The refractive index and dispersion of the above mixture films were measured by the spectral ellipsometer (VASE: available from J. A. Woollam. Co., Inc.).

The two-side reflectance and transmittance of the above mixture films were measured by the spectrophotometer (U4000: available from Hitachi, Ltd.).

Using measurements of the reflectance and

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absorption-scattering (rate) = 1 - (two-side
5 reflectance) - (transmittance).

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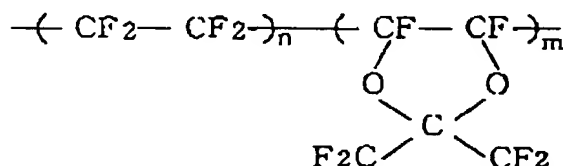
The mixture at the ratio of $\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$: amorphous fluoro-resin = 83.8:100 demonstrated large scattering with the absorption-scattering (rate) of 0.04 and the refractive index and index dispersion thereof were unmeasurable.

The refractive index and index dispersion of the mixtures at the ratios of $\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$: amorphous fluororesin = 17.3:100, 38.9:100, and 66.7:100 were $(n_d, v_d) = (1.329, 62.1)$, $(1.366, 48.9)$, and $(1.403, 42.1)$, respectively, and none of them existed in the region of $n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$.

20 The present example was different from Example 1 in that the TiO_2 particles with the refractive index and dispersion of $(n_d, v_d) = (2.2652, 11.8)$ were used instead of the particles of $\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$.

The particles of TiO_2 , the surface of which was modified with the fluorine surfactant according to [Method 2] described hereinafter, and the amorphous fluororesin ($n_d = 1.29$) represented by the chemical

formula below, were mixed at the weight ratios of TiO_2 :
amorphous fluoro-resin = 4.5:100, 9.3:100, 19:100,
39:100, 74:100, and 120:100 in the fluorine solvent
[the molecular structure of $(\text{C}_4\text{F}_9)_3\text{N}$], which was the
5 solvent in which the amorphous fluoro-resin was soluble.



10 The percentage of the amorphous fluoro-resin to the
solvent was 4%. A coating of each of the above
solutions was formed on the substrate of BK7 of $\phi 49 \times$
2t by the dip coat method and was heated in the furnace
at 180°C for 20 minutes to obtain a film of the mixture
15 of the amorphous fluoro-resin and the particles of TiO_2 .

The refractive index and dispersion of the above mixture films were measured by the spectral ellipsometer (VASE: available from J. A. Woollam. Co., Inc.).

20 The two-side reflectance and transmittance of the above mixture films were measured by the spectrophotometer (U4000: available from Hitachi, Ltd.).

Using measurements of the reflectance and
transmittance of the above mixture films, the
absorption-scattering (rate) was calculated according
to the equation below.

absorption-scattering (rate) = 1 - (two-side reflectance) - (transmittance).

The results of the refractive index and dispersion are presented in Table 2 and Fig. 10.

5 The mixture at the ratio of TiO_2 : amorphous fluororesin = 4.5:100 had the refractive index and dispersion of $(n_d, v_d) = (1.317, 48.3)$, and was off the region of $n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$. The mixture had the absorption-scattering (rate) of not
10 more than 0.01 and thus can be used as an optical film without problems.

 The mixtures at the ratios of TiO_2 : amorphous fluororesin = 9.3:100, 19:100, 39:100, and 74:100 had the refractive index and dispersion of $(n_d, v_d) =$
15 $(1.343, 34.2)$, $(1.394, 23.8)$, $(1.478, 17.8)$, and $(1.591, 14.8)$, respectively, and were within the region of $n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$. They had the absorption-scattering (rates) of not more than 0.01 and can be used as optical films without problems.

20 The mixture at the ratio of TiO_2 : amorphous fluororesin = 120:100 demonstrated great scattering with the absorption-scattering (rate) of 0.06 and the refractive index and dispersion were unmeasurable.

 In this Example 2, when compared with Example 1,
25 the region of $n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$ can be realized in the range of weight ratios of (TiO_2 : amorphous fluororesin =) 7:100 to 90:100 and, further,

the region of $n_d \leq -0.01 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$ is also realized thereby.

[Method 2] Preparation of solution in which particles of TiO_2 modified with fluorine base surfactant were dispersed

4 g of the fluorine base surfactant, N-(3-(trimethoxysilyl) propyl)-N-propylperfluorooctanesulfonamide, was added to a solution containing 20 g of TiO_2 particles (5 to 20 nm) in 500 g of 2, 2, 3, 3, 3-pentafluoro-1-propanol and thereafter 0.21 ml of 1N hydrochloric acid was added thereto. The mixture was stirred at 25°C for 24 hours to modify the surface of the particles. After that, 250 g of the fluorine solvent [the molecular structure of $(C_4F_9)_3N$] was added thereto and fractional distillation was conducted at 90°C to remove the pentafluoro propanol, and isopropanol etc. created by hydrolysis, thereby preparing the fluorine solvent solution in which the TiO_2 particles were dispersed.

<Comparative Example 2>

Comparative Example 2 was different from Example 2 in that a polymer with the refractive index ($n_d = 1.52$) was used instead of the amorphous fluororesin ($n_d = 1.29$).

The TiO_2 particles and PVA ($n_d = 1.52$) were blended at the weight ratios of TiO_2 : PVA = 2 to 200:100 in a solution (water : MeOH = 1:1). The percentage of PVA

to the solvent was 4%. A coating of each of the above solutions was formed on the substrate of BK7 of $\phi 49 \times 2t$ by the dip coat method and thereafter it was heated in the furnace at 180°C for 20 minutes, thereby obtaining a mixture film of PVA and the TiO_2 particles.

The refractive index and dispersion of the above mixture films were measured by the spectral ellipsometer (VASE: available from J. A. Woollam. Co., Inc.).

10 The two-side reflectance and transmittance of the above mixture films were measured by the spectrophotometer (U4000: available from Hitachi, Ltd.).

Using measurements of the reflectance and transmittance of the above mixture films, the absorption-scattering (rate) was calculated according to the equation below.

$$\text{absorption-scattering (rate)} = 1 - (\text{two-side reflectance}) - (\text{transmittance}).$$

20 The results of the refractive index and dispersion
are presented in Table 3 and Fig. 11.

The refractive index and dispersion of the mixtures were $(n_d, v_d) = (1.564, 33.0), (1.590, 23.9), (1.633, 18.1),$ and $(1.691, 15.2),$ neither of which was present in the region of $n_d \leq -6.667 \times 10^{-3}v_d + 1.70, v_d \leq 40.$

<Example 3>

surface of which was modified with an alkyl group for enhancing the compatibility with PMMA according to [Method 3] described hereinafter, and PMMA ($n_d = 1.48$) were mixed at the weight ratios of ITO : PMMA = 20:100, 30:100, 50:100, 120:100, 200:100, and 300:100 in methyl ethyl ketone (hereinafter referred to as MEK), which was a solvent in which PMMA was soluble. The percentage of PMMA to the solvent was 4%. A coating of each of the above solutions was formed on the substrate of BK7 of $\phi 49 \times 2t$ by the dip coat method and thereafter heated in the furnace at 80°C for 20 minutes, thereby obtaining a mixture film of PMMA and ITO particles.

The refractive index and dispersion of the above mixture films were measured by the spectral ellipsometer (VASE: available from J. A. Woollam. Co., Inc.).

The two-side reflectance and transmittance of the above mixture films were measured by the spectrophotometer (U4000: available from Hitachi, Ltd.).

Using measurements of the reflectance and transmittance of the above mixture films, the absorption-scattering (rate) was calculated according to the equation below.

absorption-scattering (rate) = $1 - (\text{two-side reflectance}) - (\text{transmittance})$.

The mixture at the weight ratio of ITO : PMMA = 20:100 demonstrated the refractive index and dispersion of $(n_d, v_d) = (1.507, 32)$, and was off the region of $n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$.

10 The mixtures at the weight ratios of ITO : PMMA =
30:100, 50:100, 120:100, and 200:100 had the refractive
index and dispersion of $(n_d, v_d) = (1.515, 26.6)$,
(1.531, 20.1), (1.571, 13.2), and (1.609, 10.2),
respectively, and were in the region of $n_d \leq -6.667 \times$
15 $10^{-3}v_d + 1.70$, $v_d \leq 40$.

The mixture at the weight ratio of ITO : PMMA = 300:100 had the refractive index and dispersion of (n_d , v_d) = (1.647, 8.6), and was off the region of $n_d \leq -6.667 \times 10^{-3} v_d + 1.70$, $v_d \leq 40$.

The chargeability was measured with an electrostatic voltmeter after each sample was wiped twenty times with wiping fabric (Savina Minimax: available from Kanebo Gosen K.K.). PMMA alone demonstrated the chargeability of 3 kV but the mixtures

[Method 3] Preparation of solution in which the ITO particles modified with alkyl group were dispersed

10 <Comparative Example 4>

15 The TiO_2 particles ($n_d = 1.29$), the surface of
which was modified with an alkyl group for enhancing
the compatibility with PMMA according to [Method 4]
described hereinafter, and PMMA were mixed at the
weight ratios of TiO_2 : PMMA = 20:100, 50:100, 85:100,
20 and 160:100 in MEK, which was a solvent in which PMMA
was soluble. The percentage of PMMA to the solvent was
4%. A coating of each of the above solutions was
formed on the substrate of BK7 of $\phi 49 \times 2t$ by the dip
coat method and thereafter was heated in the furnace at
25 80°C for 20 minutes, thereby obtaining a mixture film
of PMMA and TiO_2 particles.

The two-side reflectance and transmittance of the

Using measurements of the reflectance and
transmittance of the above mixture films, the
absorption-scattering (rate) was calculated according
to the equation below.

10 The results of the refractive index and dispersion
are presented in Table 4 and Fig. 12.

The chargeability was measured with the electrostatic voltmeter after each sample was wiped twenty times with the wiping fabric (Savina Minimax: available from Kanebo Gosen K.K.). PMMA alone demonstrated the chargeability of 3 kV. The mixtures showed the chargeability of 1 kV to 2 kV.

4 g of γ -methacryloxypropyltrimethoxysilane was added to a solution containing 20 g of TiO_2 particles (5

5 <Comparative Example 5>

10 The ITO particles and PC ($n_d = 1.59$) were mixed at
the weight ratios of ITO : PC = 20:100, 50:100, 85:100,
and 160:100 in dichloroethane. The percentage of the
solute to the solvent of dichloroethane was 4%. A
coating of each of the above solutions was formed on
15 the substrate of BK7 of $\phi 49 \times 2t$ by the dip coat method
and thereafter was heated in the furnace at 110°C for
20 minutes, thereby obtaining a mixture film of PC and
ITO particles.

The two-side reflectance and transmittance of the above mixture films were measured by the spectrophotometer (U4000: available from Hitachi, Ltd.).

Using measurements of the reflectance and

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absorption-scattering (rate) = 1 - (two-side
5 reflectance) - (transmittance).

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The mixtures had the refractive index and dispersion of $(n_d, v_d) = (1.596, 23.2), (1.614, 17.5),$
 10 $(1.628, 14.7),$ and $(1.657, 11.4),$ respectively, and
 all were off the region of $n_d \leq -6.667 \times 10^{-3}v_d + 1.70,$
 $v_d \leq 40.$

The chargeability was measured with the electrostatic voltmeter after each sample was wiped twenty times with the wiping fabric (Savina Minimax: available from Kanebo Gosen K.K.). PC alone demonstrated the chargeability of 3 kV, but the mixtures all showed no charge.

<Example 5>

20 The particles of ITO (n_d , v_d = 1.8581, 5.53), the surface of which was modified with an alkyl group for enhancing the compatibility with APO (n_d = 1.525) according to [Method 5] described hereinafter, and APO (n_d = 1.525) were mixed at the weight ratios of ITO :
25 APO = 25:100, 45:100, 70:100, 100:100, 135:100, and 220:100 in xylene, which was a solvent in which APO was soluble. The percentage of APO to the solvent was 4%.

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$$\text{absorption-scattering (rate)} = 1 - (\text{two-side reflectance}) - (\text{transmittance}).$$

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The mixture had the absorption-scattering (rate) of not more than 0.01 and can be used as an optical

The mixtures at the weight ratios of ITO : APO = 45:100, 70:100, 100:100, and 135:100 had the refractive index and dispersion of $(n_d, v_d) = (1.562, 20.5)$, $(1.580, 16.2)$, $(1.598, 13.6)$, and $(1.615, 11.8)$, respectively, and they were in the region of $n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$.

The mixtures had the absorption-scattering (rates) of not more than 0.01 and can be used as optical films without problems.

The mixture at the weight ratio of ITO : APO = 220:100 had the refractive index and dispersion of $(n_d, v_d) = (1.650, 9.63)$, and was off the region of $n_d \leq 6.667 \times 10^{-3} v_d + 1.70, v_d \leq 40$.

15 The chargeability was measured with the
electrostatic voltmeter after each sample was wiped
twenty times with the wiping fabric (Savina Minimax:
available from Kanebo Gosen K.K.). APO alone
demonstrated the chargeability of 3 kV, but the
20 mixtures all showed no charge.

[Method 5] Preparation of solution in which ITO particles modified with alkyl group were dispersed

4 g of β -(3, 4 epoxycyclohexyl)
ethyltrimethoxysilane was added to a solution
25 containing 20 g of ITO particles (5 to 20 nm) in 500 g
of n-butanol, and thereafter 0.2 ml of 1N hydrochloric
acid was added thereto. The mixture was stirred at

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<Example 6>

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5      absorption-scattering (rate) = 1 - (two-side
      reflectance) - (transmittance).
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The mixture at the weight ratio of ITO : MS = 25:100 had the refractive index and dispersion of $(n_d, v_d) = (1.555, 24.1)$, and was off the region of $n_d \leq -6.667 \times 10^{-3} v_d + 1.70, v_d \leq 40$.

The mixtures at the weight ratios of ITO : MS = 45:100, 70:100, 100:100, and 135:100 had the refractive index and dispersion of $(n_d, v_d) = (1.569, 19.2)$, $(1.587, 15.5)$, $(1.604, 13.2)$, and $(1.621, 11.6)$, respectively, and they were in the region of $n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$.

25 The mixture at the weight ratio of ITO : MS = 220:100 had the refractive index and dispersion of $(n_d, v_d) = (1.655, 9.51)$, and was off the region of $n_d \leq$

$$-6.667 \times 10^{-3}v_d + 1.70, v_d \leq 40.$$

The chargeability was measured with the electrostatic voltmeter after each sample was wiped twenty times with the wiping fabric (Savina Minimax: available from Kanebo Gosen K.K.). PC alone demonstrated the chargeability of 3 kV, but the mixtures all showed no charge.

<Example 7>

The optical material adjusted to $(n_d, v_d) = (1.531, 20.1)$ by mixing PMMA and ITO particles at the weight ratio of ITO : PMMA = 50:100 as described in Example 4, was combined with PSK50: $(n_d, v_d) = (1.5938, 60.9)$ available from Sumita Kogaku Kogyo, in the structure illustrated in Fig. 8. The height d of the grating was 9.98 μm and the diffraction efficiency was not less than 98% for the light at the wavelengths in the visible region of 400 to 700 nm.

The height of the grating was approximately two thirds of that in Comparative Example 3 and this is advantageous in terms of forming of lens.

The chargeability was measured with the electrostatic voltmeter after the sample was wiped twenty times with the wiping fabric (Savina Minimax: available from Kanebo Gosen K.K.). The sample showed no charge.

<Comparative Example 6>

The conventional material of p-methoxybenzyl

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<Example 8>

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5 The refractive index and dispersion of the above
mixture films were measured by the spectral
ellipsometer (VASE: available from J. A. Woollam. Co.,
Inc.).

Using measurements of the reflectance and transmittance of the above mixture films, the absorption-scattering (rate) was calculated according to the equation below.

The results of the refractive index and dispersion
20 are presented in Table 6 and Fig. 14.

The mixtures had the absorption-scattering (rates) of not more than 0.01 and can be used as optical films

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The mixture had the absorption-scattering (rate) of 0.02.

2.5

[Method 6] Preparation of solution in which TiO_2 particles modified with functional group of silicone

were dispersed

4 g of the silicone base surfactant was added to a solution containing 20 g of TiO_2 particles (5 to 20 nm) in 500 g of n-butanol, and thereafter 0.2 ml of 1N hydrochloric acid was added thereto. The solution was stirred at 25°C for 24 hours to modify the surface of the particles.

After that, 250 g of n-heptane was added to the solution and the fractional distillation was conducted at 100°C to remove n-butanol, and alcohols etc. created by hydrolysis, thereby preparing the n-heptane solution in which the TiO_2 particles were dispersed.

The optical materials prepared according to the above method of the present embodiment are used for the optical systems such as image pickup optical systems, projection optical systems, illumination systems, and so on, or for the optical devices such as cameras, microscopes, binoculars, and so on.

Each of the above examples permits attainment of the optical materials satisfying the region ($n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$) or $n_d \leq -0.01v_d + 1.70$, $v_d \leq 40$ and being indispensable for performance enhancement of the refracting optical systems and stack optical elements, and the optical systems using it.

Particularly, the optical material satisfying the low-index high-dispersion region ($n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$) can be realized by mixing the low-index

material ($n_d \leq 1.45$) with the large-dispersion material ($v_d \leq 25$) as described above.

In that case, the optical material can be one better satisfying the region ($n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$) where the particles (2 to 100 nm) of the composite metal oxide of titanium and silicon ($\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$) ($v_d = 24.4$) are used as the large-dispersion material, the amorphous fluororesin ($n_d = 1.29$ to 1.38) is used as the low-index material, and they are mixed in the weight ratio range of ($\text{Si}_x\text{-Ti}_{(1-x)}\text{O}_2$: fluororesin) of 45:100 to 75:100.

Further, the low-index high-dispersion region ($n_d \leq -0.01v_d + 1.70$, $v_d \leq 40$) can be realized by mixing the low-index material ($n_d \leq 1.40$) with the particles of the large-dispersion material ($v_d \leq 15$).

In that case, the low index and high dispersion tendency is enhanced more where the particles (2 to 100 nm) of TiO_2 (n_d , $v_d = 2.2652$, 11.8) are used as the large-dispersion material, the amorphous fluororesin ($n_d = 1.29$ to 1.38) as the low-index material, and they are mixed in the weight ratio range of (TiO_2 : fluororesin) of 7:100 to 90:100.

This permits the supply of the optical materials in the region ($n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$) and in the region ($n_d \leq -0.01v_d + 1.70$, $v_d \leq 40$) and thus facilitates achievement of higher performance of the optical systems such as the refracting optical systems,

the stack optical elements, and so on.

The low-index high-dispersion region ($n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$) can also be realized by mixing the low-index material ($1.45 \leq n_d \leq 1.55$) with the large-dispersion material ($v_d \leq 10$) as described above.

In that case, the optical material can be one better satisfying the region ($n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$) where the particles (2 to 100 nm) of ITO ($v_d = 5.53$) are used as the large-dispersion material, either polymethyl methacrylate (PMMA, $n_d = 1.48$), amorphous polyolefin (APO, $n_d = 1.525$), or the copolymer of methyl methacrylate and styrene (MS, $n_d = 1.533$) as the low-index material, and they are mixed in the weight ratio range of (ITO : PMMA) of 30:100 to 250:100, in the weight ratio range of (ITO : APO) of 44:100 to 150:100, or in the weight ratio range of (ITO : MS) of 43:100 to 140:100.

This permits the supply of the optical materials in the region ($n_d \leq -6.667 \times 10^{-3}v_d + 1.70$, $v_d \leq 40$) by use of the materials of $1.45 \leq n_d \leq 1.55$ such as PMMA ($n_d = 1.48$), APO ($n_d = 1.525$), MS ($n_d = 1.533$), etc. which are commonly used as optical materials, and thus facilitates achievement of higher performance of the refracting optical systems and stack diffracting optical elements.

At the same time, since ITO is the electroconductive substance, it can reduce the

[illegible][illegible]

Table 1

	Refractive Index and Abbe's Number of SiO ₂ - TiO ₂ (n_d , v_d)	Weight Ratio (Si _x -Ti _(1-x) O ₂ : TefronAF)	Refractive Index n_d	Abbe's Number v_d	Absorption / Scattering ($\lambda=500\text{nm}$) = 1 - (Transmittance) - (Two-side Reflectance)
Example 1	1.703, 24.4	18.3 : 100	1.337	53.9	less than 0.005
		41.1 : 100	1.383	41.0	less than 0.005
		70.5 : 100	1.427	34.9	less than 0.005
		88.5 : 100	----	----	0.04
Comparative Example 1	1.636, 29.1	17.3 : 100	1.329	62.1	less than 0.005
		38.9 : 100	1.366	48.9	less than 0.005
		66.7 : 100	1.403	42.1	less than 0.005
		83.8 : 100	----	----	0.04

Table 2

	Weight Ratio (TiO ₂ : TefronAF)	Refractive Index n_d	Abbe's Number v_d	Absorption / Scattering ($\lambda=500\text{nm}$) = 1 - (Transmittance) - (Two-side Reflectance)
Example 2	4.5 : 100	1.317	48.3	less than 0.005
	9.3 : 100	1.343	34.2	less than 0.005
	19 : 100	1.394	23.8	less than 0.005
	39 : 100	1.478	17.8	less than 0.005
	74 : 100	1.591	14.8	0.007
	120 : 100	----	----	0.06

Table 3

	Weight Ratio (TiO ₂ : Polymer)	Refractive Index n_d	Abbe's Number v_d	Absorption / Scattering ($\lambda=500\text{nm}$) = 1 - (Transmittance) - (Two-side Reflectance)
Comparative Example 2	14.8 : 100	1.564	33.0	less than 0.005
	29.6 : 100	1.590	23.9	less than 0.005
	59.3 : 100	1.633	18.1	less than 0.005
	103.7 : 100	1.691	15.2	0.007

	High Disperse Material and Low Refraction Material, and their Index and Abbe's Number (n_d, v_d)	Weight Ratio (High Disperse Material : Low Refraction Material)	Refractive Index n_d	Abbe's Number v_d	Absorption / Scattering ($\lambda=500\text{nm}$) = 1 · (Transmittance) - (Two-side Reflectance)
Example 4	ITO $(n_d, v_d = 1.8581, 5.53)$ PMMA $(n_d, v_d = 1.490, 57.6)$	20 : 100	1.5065	32.1	less than 0.005
		30 : 100	1.5146	26.6	less than 0.005
		50 : 100	1.5308	20.1	less than 0.005
		120 : 100	1.5705	13.2	less than 0.005
		200 : 100	1.6093	10.2	less than 0.005
		300 : 100	1.6471	8.65	0.01
Comparative Example 4	TiO ₂ $(N_d, v_d = 2.265, 11.8)$ PMMA $(N_d, v_d = 1.490, 57.6)$	20 : 100	1.5190	40.2	less than 0.005
		50 : 100	1.5847	25.9	less than 0.005
		85 : 100	1.6300	21.7	less than 0.005
		160 : 100	1.7169	17.5	less than 0.005
Comparative Example 5	ITO $(N_d, v_d = 1.8581, 5.53)$ PC $(N_d, v_d = 1.58, 30.5)$	20 : 100	1.5961	23.2	less than 0.005
		50 : 100	1.6137	17.5	less than 0.005
		85 : 100	1.6282	14.7	less than 0.005
		160 : 100	1.6569	11.4	less than 0.005

[illegible]

Table 5

	High Disperse Material and Low Refraction Material, and their Index and Abbe's Number (n_d, v_d)	Weight Ratio (High Disperse Material : Low Refraction Material)	Refractive Index n_d	Abbe's Number v_d	Absorption / Scattering ($\lambda=500\text{nm}$) = 1 - (Transmittance) - (Two-side Reflectance)
Example 5	ITO ($n_d, v_d = 1.8581, 5.53$) APO ($n_d, v_d = 1.525, 52.1$)	25 : 100	1.548	26.6	less than 0.005
		45 : 100	1.562	20.5	less than 0.005
		70 : 100	1.580	16.2	less than 0.005
		100 : 100	1.598	13.6	less than 0.005
		135 : 100	1.615	11.8	less than 0.005
		220 : 100	1.650	9.63	0.01
Example 6	ITO ($n_d, v_d = 1.8581, 5.53$) MS ($n_d, v_d = 1.534, 41.5$)	25 : 100	1.555	24.1	less than 0.005
		45 : 100	1.569	19.2	less than 0.005
		70 : 100	1.587	15.5	less than 0.005
		100 : 100	1.604	13.2	less than 0.005
		135 : 100	1.621	11.6	less than 0.005
		220 : 100	1.655	9.51	0.01

Table 6

	Weight Ratio (TiO ₂ : Dimethyl Silicone)	Refractive Index n_d	Abbe's Number v_d	Absorption / Scattering ($\lambda=500\text{nm}$) = 1 - (Transmittance) - (Two-side Reflectance)
Example 8	5 : 100	1.440	44.6	less than 0.005
	10 : 100	1.450	39.9	less than 0.005
	20 : 100	1.471	33.5	less than 0.005
	38 : 100	1.502	27.7	less than 0.005
	55 : 100	1.533	24.2	less than 0.005
	88 : 100	1.582	20.6	0.02